Research Report

Effect of a Tone-Inhibiting Dynamic Ankle-Foot Orthosis on Stride Characteristics of an Adult with Hemiparesis

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A single-subject, alternating-treatment design was used to investigate differences in stride characteristics of a hemiparetic subject under three conditions: 1) barefoot, 2) using a prefabricated plastic molded ankle-foot orthosis (AFO), and 3) using a tone-inhibiting dynamic ankle-foot orthosis (TIAFO). Five barefoot baseline sessions were conducted. Following these baseline sessions, the three conditions were randomly varied during each of 12 alternating-treatment sessions. Data analysis revealed a significant improvement in walking velocity, step length, and stance time on the hemiparetic limb and a significant decrease in cadence when either the AFO or the TIAFO condition was compared with the barefoot condition. The TIAFO was associated with a significant increase in walking velocity and step length when evaluated against the prefabricated AFO. The subject reported that use of the TIAFO increased his ability to ambulate distances and that the TIAFO was more comfortable and less restrictive than the prefabricated AFO. The results suggest that the TIAFO may be a promising alternative to conventional orthotic management of adults with hemiparesis. [Diamond MF, Ottenbacher KJ. Effect of a tone-inhibiting dynamic ankle-foot orthosis on stride characteristics of an adult with hemiparesis. Phys Ther. 1990;70:423–430.]

Key Words: *Hemiplegia, gait; Hemiplegia, orthoses and supports; Kinesiology/biomechanics, gait analysis; Orthotics/splints/casts, lower extremity.*

The use of orthoses to assist with ambulation in patients with neurological deficits is a common rehabilitation practice. Therapists frequently prescribe the use of ankle-foot orthoses (AFOs) for patients with gait deficits attributable to cerebrovascular accident (CVA) or other central nervous system disorders. Because the gait pattern of hemiplegic patients is extremely variable from patient to patient and often varies considerably within the same individual,[1] determination of the best orthosis for a patient is difficult. Factors such as limited range of motion, hyperreflexia, decreased voluntary control over motor patterns, edema, sensory deficits, and instability of the ankle and other joints of the lower extremity must be considered in the evaluation and prescription of an orthosis.[2]

Many different types of orthoses are available, but few efficacy studies exist, making selection of the most effective orthoses difficult. Corcoran and associates[3] found that use of an AFO reduced energy consumption in hemiplegic patients, but that the difference in energy consumption between metal and plastic orthoses was neither statistically nor clinically significant. In a study comparing the effect of stopping the ankle joint of an AFO at 5 degrees of dorsiflexion or at 5 degrees of plantar flexion, Lehmann and colleagues[4] found that gait speed was significantly increased with the ankle joint stopped at either position and that the speed achieved with the AFO in dorsiflexion was significantly greater than with it in plantar flexion. Effectiveness of the Air-Stirrup® ankle

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brace* was compared with that of metal and plastic AFOs in a study by Burdett and colleagues.[5] Use of an AFO compared with either use of the Air-Stirrup® or use of no orthosis was associated with a significant decrease in plantar flexion at foot-strike and mid-swing; use of the Air-Stirrup® compared with use of no orthosis resulted in a significant decrease in plantar flexion at toe-off and mid-swing; and use of the Air-Stirrup® resulted in less inversion at foot-strike and less calcaneal motion during the stance phase of gait than when the Air-Stirrup® was not used.[5]

Early descriptions of orthotic techniques emphasized management of gait abnormalities, primarily through positioning of the ankle joint in dorsiflexion or plantar flexion and controlling the excursion of the ankle joint in an anterior-posterior direction during gait.[6] More recently, in working with children with cerebral palsy, Cusick and Sussman[7] and Hylton and Uhri[8] have taken a different approach to providing assistance with gait. These authors recommended the use of modified shoes, casts, and orthoses as an adjunct to the development of movement control through factors such as improved alignment of the structures of the foot, ankle, and toes; resultant improved alignment of proximal structures; and improved weight distribution through the foot with facilitation of effective weight transfer, control of abnormal reflexes, and improved stability of the base of support in standing and walking, resulting in diminished need for use of compensatory stabilization proximally.

Although the use of inhibitory methods of lower extremity control is accepted with children, as documented by Cusick and Sussman[7] and Harris and Riffle,[9] the orthotic management of adults with neurological deficits and hyperreflexia is still limited primarily to standard methods such as use of the single or double upright metal orthosis and use of the plastic molded AFO. Initial application of inhibitive principles of orthotic management with adults has been documented in a case study by Zachazewski et al.[10] Although the case study and anecdotal clinical evidence suggest that inhibitory methods of lower extremity control may be successful with adults, more objective documentation is needed to further substantiate the use of this type of device with adults.

Holden and associates[11] found that velocity is a good measure of gait because it is a composite of several other time and distance variables. Asymmetry of stance is a common clinical observation in the gait pattern of hemiplegic patients, characterized by longer-than-normal stance on the uninvolved lower extremity and shorter-than-normal stance on the hemiplegic lower extremity. Although it is not well correlated with functional level, asymmetry of stance appears to correlate with motor recovery patterns.[11]

The purpose of this study was to compare four stride characteristics of a subject with hemiparesis under three conditions: 1) barefoot, 2) using a standard prefabricated AFO, and 3) using a tone-inhibiting dynamic ankle-foot orthosis (TIAFO). Stride characteristics assessed were walking velocity, step length, cadence, and stance time on the hemiparetic lower extremity. We used a single-subject, alternating-treatment design to compare each of the stride characteristics between conditions. Based on available literature and clinical experience, we hypothesized that the TIAFO would be associated with the most normal stride.

Method

Subject

The subject was a 32-year-old man who had suffered a CVA with resultant right hemiparesis and aphasia. Two months after the CVA, he was seen in an orthotic clinic for recommendation and prescription of an AFO. His observed gait deviations at that time consisted of mild hip hiking, posterior tilting of the pelvis, and circumduction of the affected lower extremity during the swing phase of gait. Decreased hip and knee flexion and lack of active dorsiflexion were also noted during swing on the affected side. At that time, the subject used a standard cane and demonstrated decreased weight shift onto the affected side. He received a standard prefabricated polypropylene AFO, which was considered to be the most appropriate orthotic device for controlling his gait deviations. The AFO was narrow over the area of the Achilles tendon and was secured with a strap at the proximal calf.

After approximately 3 months' use, the subject discontinued use of the AFO, stating that it was restrictive and limiting. At 9 months post-CVA, the subject requested a consultation with the orthotic clinic because of awkwardness during ambulation and pain in the right thigh after ambulating approximately one block. Gait deviations observed at that time included decreased hip and knee flexion, no visible active dorsiflexion of the right ankle, and compensation for these deficits through posterior tilting of the pelvis and circumduction of the right lower extremity during swing. The subject did not require physical assistance or an assistive device for ambulation. He demonstrated partial control of active isolated movements of the right hip, knee, and ankle.

Orthosis

A TIAFO was prescribed for the subject at this time as the best way to control his alignment and correct various gait abnormalities. Following a thorough evaluation, a contoured, custom-made footboard was fabricated and incorporated into the casting for the TIAFO. The TIAFO was molded of flexible polypropylene and provided support around most of the foot, extending distally under the toes and proximally (posteriorly and later-

*Aircast Inc, PO Box T, Summit, NJ 07901.

ally) to about mid-calf (Fig. 1). A strap across the front of the ankle at a 45-degree angle from the heel secured the TIAFO to the subject's lower limb, keeping the calcaneus in place with the subtalar joint in normal biomechanical alignment. A calf strap was not used, thus ensuring that dorsiflexion would not be restricted. The TIAFO is custom-made (individualized) for each patient and designed to provide firm, but flexible, control. It supports the arches of the foot and provides stability, lessening the patient's need for use of abnormal balance and compensation patterns.

The subject was 10 months post-CVA at the time of this study. He had received two therapy sessions for evaluation and training with the orthosis, but he did not receive therapy during the time this study took place. The TIAFO and the subject's prefabricated AFO were the orthotic devices used in this study.

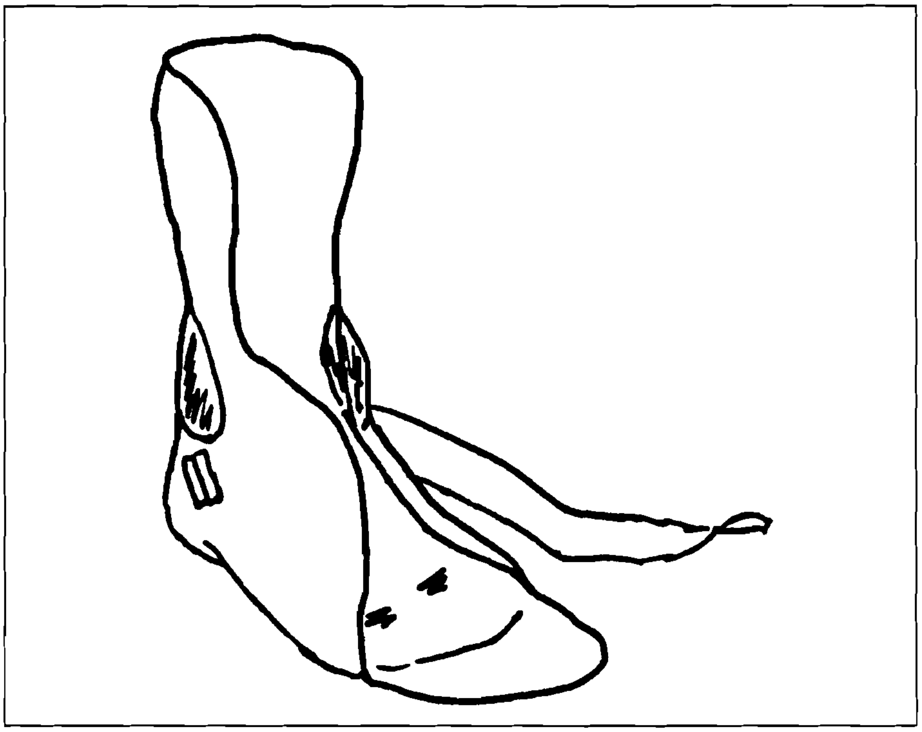

Fig. 1. *Line drawing of tone-inhibiting dynamic ankle-foot orthosis.*

Research Design

A single-subject, alternating-treatment design similar to the research design used by Harris and Riffle[9] was used to compare stride characteristics of gait in each of three conditions:
1) barefoot ambulation, 2) ambulation with the prefabricated AFO, and
3) ambulation using the custom-fabricated TIAFO.

An initial baseline phase, consisting of measurements of each of the stride characteristics across 5 sessions and across 7 days with the subject barefoot, was conducted to establish a pretreatment level of performance for comparison.[12] The barefoot condition was considered the most natural baseline strategy and avoided the problems introduced by the use of different types of footwear. During the alternating-treatment phase, the three conditions (barefoot, traditional AFO, and TIAFO) were verified randomly within each of 12 measurement sessions. The 12 measurement sessions were conducted over a period of 1 month. No more than 2 sessions were conducted on the same day, and no more than 4 days elapsed between measurement sessions. At each measurement session, stride characteristics were recorded for each of the three conditions, which were varied according to a randomly determined sequence. At the conclusion of the alternating-treatment phase of the study, 4 additional measurements of the barefoot condition were taken across 6 days, comprising a follow-up phase.

Measurement Procedure

The Electrodynogram (EDG) system[†] was used to measure gait characteristics. The EDG is a computerized system of collecting and analyzing data as a subject walks for a period of about 30 seconds. Seven thin force sensors are attached to each of the subject's feet. The sensors are connected by a cable to a data-collection device worn around the subject's waist. The subject is instructed to walk at a comfortable speed and is unaware of the portion of the gait cycle that is being recorded. Following data collection, the information is transferred via another cable from the data-collection device to an IBM[‡] or IBM-compatible computer. The EDG software analyzes the data and generates a detailed readout, which includes, in part, the subject's cadence and the percentage of the gait cycle spent in stance and swing on each foot.[13]

The EDG data-collection device and remote activator were calibrated immediately prior to the study. Data on the accuracy of the EDG system were not collected as part of this study. Manufacturer's claims relative to the system's ability to measure the gait variables were not verified in this study. We believe data collection was improved through the use of permanent markers to indicate sensor placement on the bottom of the subject's feet. This procedure ensured replica-

[†]The Langer Biomechanics Group, 21 E Industry Ct, Deer Park, NY 11729.

[‡]International Business Machines Corp, 1000 NW 51st St, Boca Raton, FL 33432.

ble placement of the sensors during each measurement session. The subject wore socks during all trials to help ensure the reliability of the data by protecting the EDG pressure sensors.

Walking velocity (in meters per second) was measured by timing the subject with a stopwatch as he walked 11 m. Reliability of the velocity measurement was assessed by having two therapists record the time for the subject to ambulate a distance of 11 m during baseline trials. An interrater correlation coefficient of .99 was obtained over a total of 10 trials. The interrater reliability was computed using a Pearson product-moment correlation coefficient. The analysis included a comparison of mean values to ensure that parallelism was not influencing the result.

Average step length was computed by dividing walking velocity (in meters per second) by cadence (in steps per minute) and multiplying by 60 seconds per minute. Cadence and percentage of the gait cycle spent in stance on the hemiparetic lower extremity were obtained directly from the EDG system print-out for each of the subject's ambulation trials.

The study began 3½ weeks after the subject received the TIAFO and 2 weeks after the last treatment session. At that time, we believed that any learning response to the use of the new TIAFO had taken place. The subject reported feeling comfortable using the TIAFO, and no loss of balance or hesitation during ambulation was observed. An informed consent form was signed by the subject.

The study was conducted in a little-used hallway in a rehabilitation facility, and measurements were recorded only when there was no traffic or distraction. The hallway was 40 m in length, or approximately three times as long as the distance required for either the EDG recording or the walking velocity measurement. For each measurement, the subject was instructed to walk down the hall in a comfortable and normal manner and was allowed to walk about 5 m before the data collection was initiated.

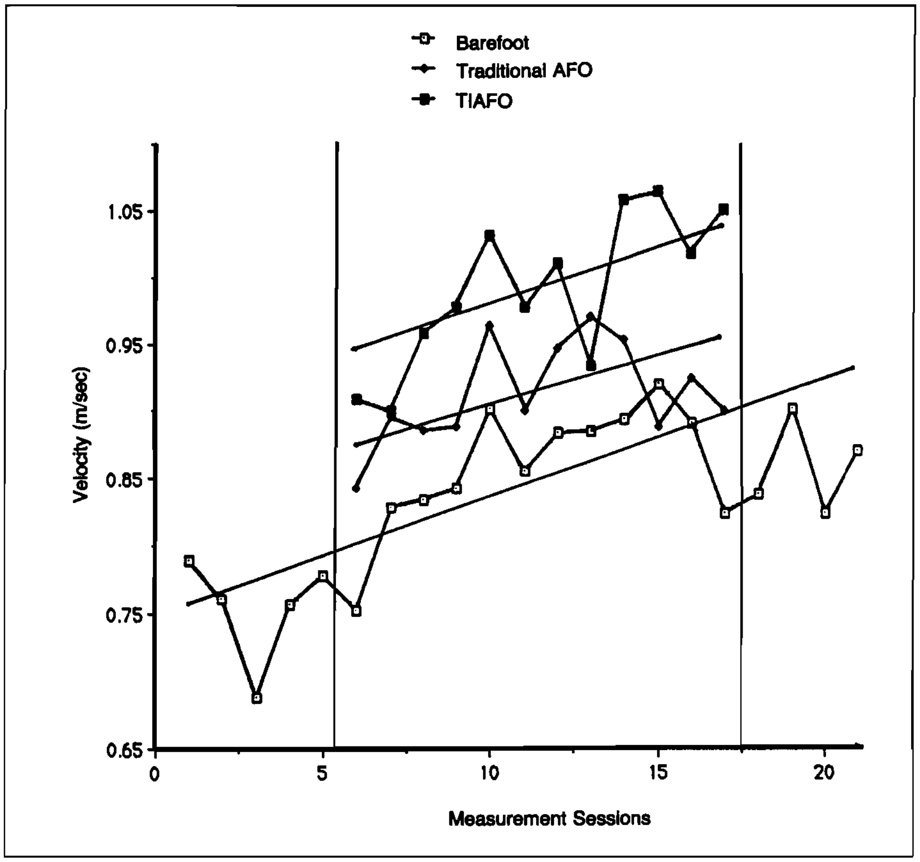

Fig. 2. *Ambulation velocity (in meters per second) of one hemiparetic subject across three conditions (barefoot ambulation, ambulation with a prefabricated ankle-foot orthosis [AFO], and ambulation with a tone-inhibiting dynamic ankle-foot orthosis [TIAFO]) over 21 measurement sessions.*

Data Analysis

All data were graphed and celeration lines computed using the split-middle method of trend estimation. Statistical significance was determined using the celeration line in conjunction with a probability table ($p < .05$).[12] In addition, the percentage of overlap between conditions for each dependent variable was calculated as outlined by Tawney and Gast.[14]

Results

The walking velocity data are presented in Figure 2. Walking velocity with the prefabricated AFO was found to be significantly faster than in the barefoot condition when the data from the prefabricated AFO and baseline celeration lines were compared using the probability table.[12] Walking velocity with the TIAFO was significantly faster than in the barefoot condition and also significantly faster than with the prefabricated AFO. Mean velocities for the baseline, prefabricated AFO, and TIAFO conditions were 0.83, 0.91, and 0.99 m/sec, respectively. In comparing percentage of overlap for walking velocity, the prefabricated AFO condition overlapped the barefoot condition by 58%. The TIAFO condition overlapped the prefabricated AFO condition by 33%, but it overlapped the barefoot condition by only 17%.

Celeration lines for step length, computed from walking velocity and cadence measurements, are presented in Figure 3. Use of the prefabricated AFO resulted in an average step length that was significantly longer

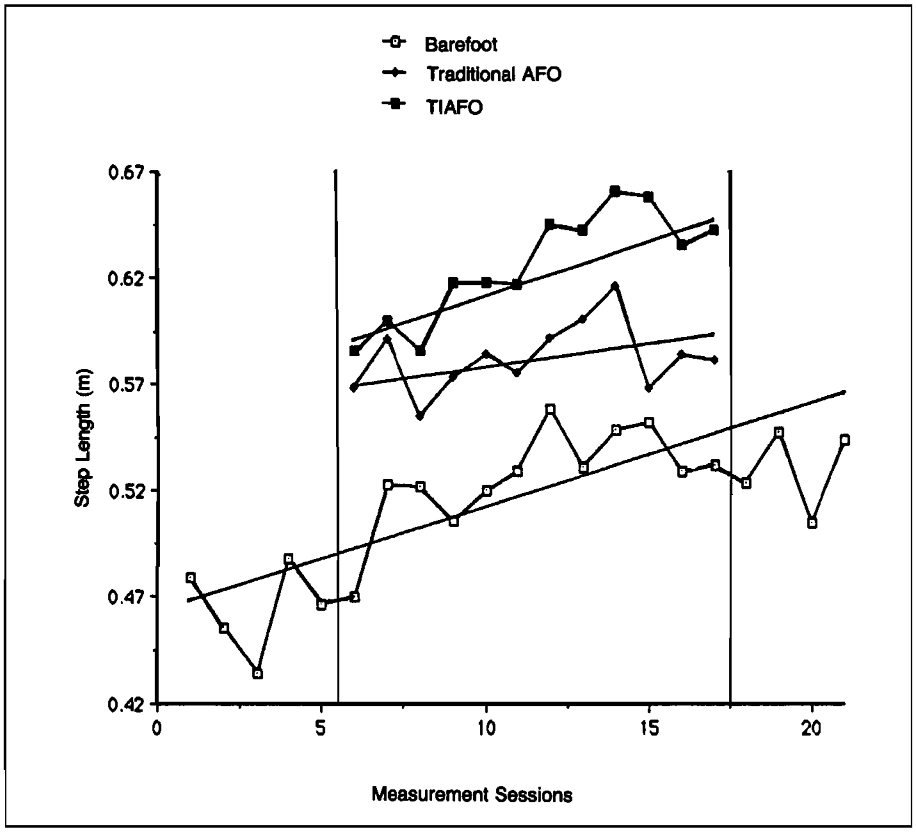

Fig. 3. *Average ambulation step length (in meters) of one hemiparetic subject across three conditions (barefoot ambulation, ambulation with a prefabricated ankle-foot orthosis [AFO], and ambulation with a tone-inhibiting dynamic ankle-foot orthosis [TIAFO]) over 21 measurement sessions.*

Table 1. *Statistical Significance[a] of Comparisons Among Three Conditions for Stride Characteristics of One Hemiparetic Subject, Obtained Using Celeration Lines and a Probability Table[12]*

	Stride Characteristic			
Conditions Compared	**Walking Velocity**	**Step Length**	**Cadence**	**Stance Time on Hemiparetic Lower Extremity**
TIAFO[b] vs Barefoot	+	+	+	+
TIAFO vs Prefabricated AFO[c]	+	+	0	0
Prefabricated AFO vs Barefoot	+	+	+	+

[a] + = significant ($p < .05$); 0 = not significant ($p > .05$).

[b] TIAFO = tone-inhibiting dynamic ankle-foot orthosis.

[c] AFO = ankle-foot orthosis.

than in the barefoot condition (0.58 vs 0.51 m), as evidenced by using celeration lines in combination with the probability table. With the TIAFO, the subject's average step length (0.63 m) was significantly longer than when walking barefoot and also significantly longer than when using the prefabricated AFO. The prefabricated AFO condition overlapped the barefoot condition by 42%. Step-length values for the TIAFO condition overlapped those for the prefabricated AFO condition by 50%, but demonstrated no overlap with the barefoot condition.

The celeration lines demonstrate that cadence was significantly less in both the TIAFO and the prefabricated AFO conditions with respect to the barefoot condition (Fig. 4). Mean cadence was 97.7 steps/min for the barefoot condition, 94.9 steps/min with the TIAFO, and 94.2 steps/min with the prefabricated AFO. Comparison of percentages of overlap revealed relatively great overlap between all conditions. The prefabricated AFO and the TIAFO conditions overlapped the barefoot condition by 79% and 71%, respectively. There was no significant difference between the range of cadence with the TIAFO and with the prefabricated AFO, although cadence with the TIAFO had a slightly wider range.

Similar analysis for stance time on the hemiparetic lower extremity (Fig. 5) revealed that use of either orthotic device resulted in significantly longer stance on the hemiparetic lower extremity (mean stance time = 60% of the gait cycle for both orthotic conditions) than walking barefoot (mean stance time = 57% of the gait cycle). The prefabricated AFO and TIAFO conditions overlapped the barefoot condition by 42% and 50%, respectively. The prefabricated AFO condition overlapped the TIAFO condition by 83%, suggesting relatively little difference in performance between the two orthotic conditions for this particular outcome measure.

In summary, significant differences in walking velocity, step length, cadence, and stance time on the hemiparetic extremity were found for use of the TIAFO and the prefabricated AFO when compared with the barefoot condition. Walking velocity and step length were significantly superior with the TIAFO in comparison with the prefabricated AFO (Table 1). In reviewing the percentages of overlap

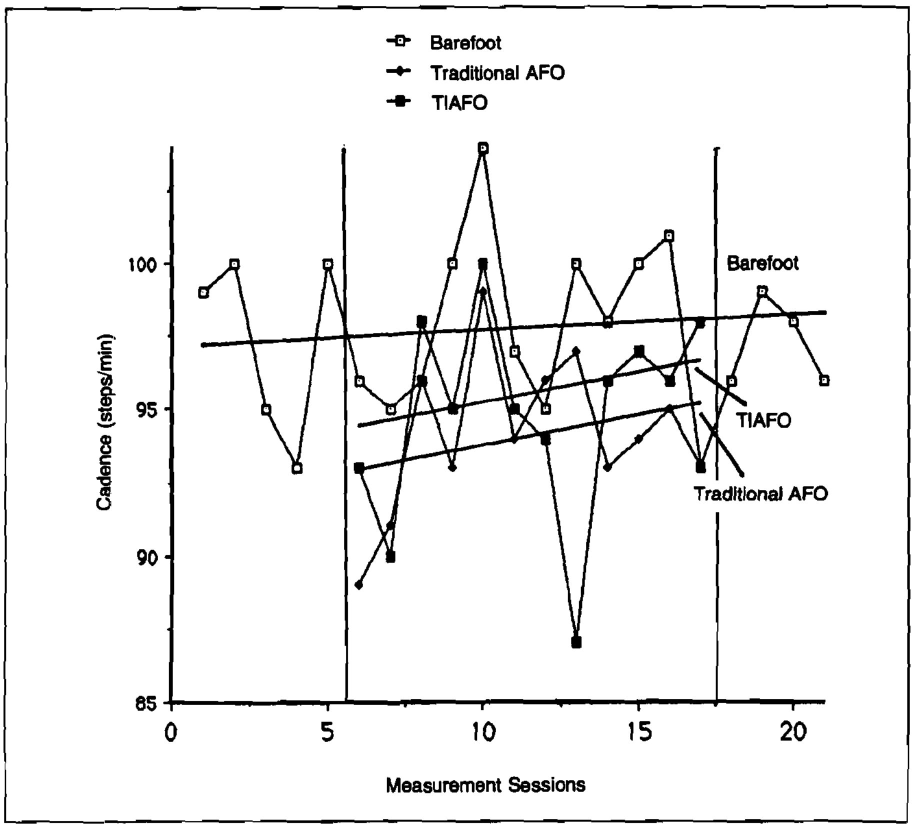

Fig. 4. *Ambulation cadence (in steps per minute) of one hemiparetic subject across three conditions (barefoot ambulation, ambulation with a prefabricated ankle-foot orthosis [AFO], and ambulation with a tone-inhibiting dynamic ankle-foot orthosis [TIAFO]) over 21 measurement sessions.*

Table 2. *Percentages of Overlap of Comparisons Among Three Conditions for Stride Characteristics of One Hemiparetic Subject Across 21 Measurement Sessions*

	Stride Characteristic			
Conditions Compared	**Walking Velocity**	**Step Length**	**Cadence**	**Stance Time on Hemiparetic Lower Extremity**
TIAFO[a] vs Barefoot	17	0	71	50
TIAFO vs Prefabricated AFO[b]	33	50	100	83
Prefabricated AFO vs Barefoot	58	42	79	42

[a]TIAFO = tone-inhibiting dynamic ankle-foot orthosis.

[b]AFO = ankle-foot orthosis.

for the four dependent measures (Table 2), the greatest differences were found between the TIAFO and barefoot conditions for step length (0% overlap) and walking velocity (17% overlap) and between the TIAFO and prefabricated AFO conditions for walking velocity (33% overlap).

Discussion

The subject's mean walking velocity approached what we consider to be a normal value of 1.51 m/sec as he proceeded from the barefoot condition, to the prefabricated AFO condition, to the TIAFO condition (Table 3).[15] Wall and Ashburn[16] state that an increase in walking velocity can be achieved by increasing cadence or by increasing stride length and that it is usually achieved by a combination of both. In our study, the subject's cadence decreased while step length increased, resulting in an overall increase in walking velocity.

During barefoot ambulation, the mean stance time on the hemiparetic extremity was 57% of the gait cycle, but with either the prefabricated AFO or the TIAFO, the mean stance time was 60% of the gait cycle. This value compares favorably with the expected value of 61% reported by Murray et al[17] for normal gait in men.

Because a prefabricated orthosis, by definition, may not fit an individual as well as a custom-made device, it could be argued that lack of fit caused the prefabricated AFO to be less effective than the custom-molded TIAFO in this study. Neither the subject nor the orthotic clinic, however, reported poor fit of the prefabricated AFO to be a problem at any time.

A common clinical assumption regarding ambulation in patients with CNS damage is that as the patient ambulates longer distances, increases speed of ambulation, and requires less assistance of a cane or other device, he or she will need less support from an orthosis. This study demonstrated, however, that an orthosis designed to provide more control and stability can be more effective than one with less control for an individual at a relatively high level of function. The TIAFO appeared to provide necessary control for factors that are essential to efficient ambulation.

The TIAFO is similar in fabrication and use to inhibitory casting. Clinical documentation exists for the effective-

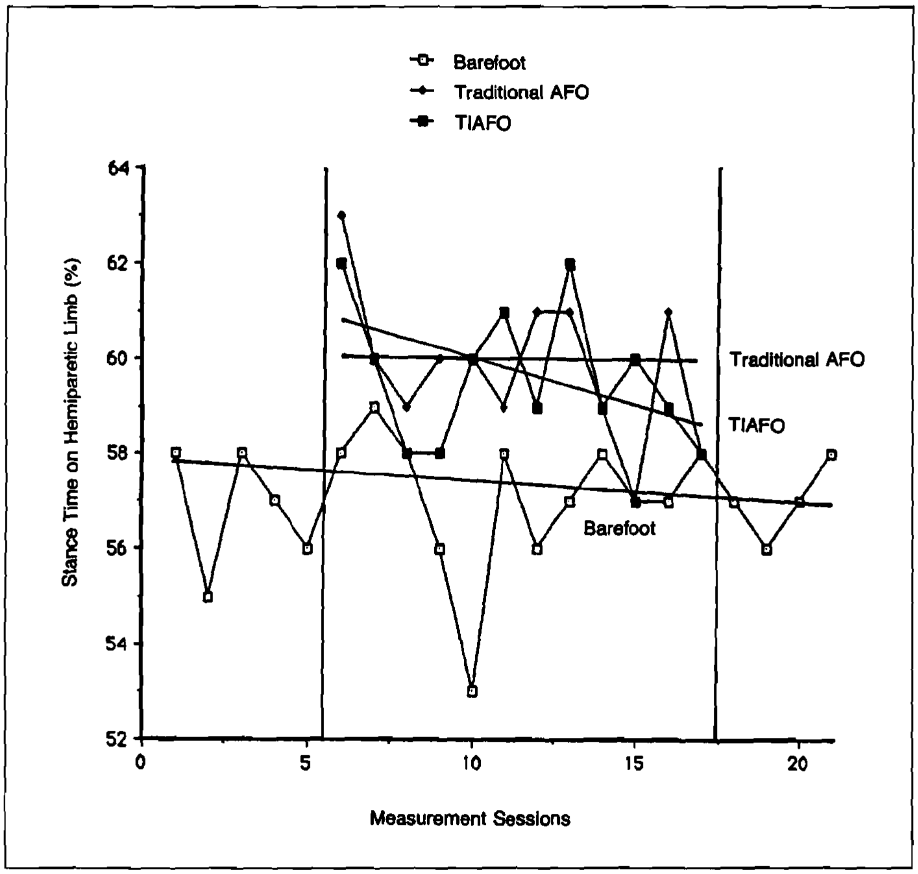

Fig. 5. *Stance time (as percentage of gait cycle) on hemiparetic limb for one hemiparetic subject across three conditions (barefoot ambulation, ambulation with a prefabricated ankle-foot orthosis [AFO], and ambulation with a tone-inhibiting dynamic ankle-foot orthosis [TIAFO]) over 21 measurement sessions.*

Table 3. *Mean Values of Stride Characteristics of One Hemiparetic Subject Across Three Conditions Over 21 Measurement Sessions*

	Condition		
Stride Characteristic	**Barefoot**	**Prefabricated AFO**[a]	**TIAFO**[b]
Walking velocity (m/sec)	0.83	0.91	0.99
Average step length (m)	0.51	0.58	0.63
Cadence (steps/min)	97.7	94.2	94.9
Stance time on hemiparetic lower extremity (% of gait cycle)	57	60	60

[a]AFO = ankle-foot orthosis.

[b]TIAFO = tone-inhibiting dynamic ankle-foot orthosis.

ness of both therapeutic adjuncts in reducing abnormally increased muscle activity and improving function.[7,10]

The neurophysiological principles that are believed to underlie the success of inhibitory casting include 1) positioning of the ankle plantar flexors and long toe flexors to provide prolonged stretch, 2) pressure on tendons of the long toe flexors, 3) prevention of reflexes induced by tactile stimulation, 4) influence on proprioceptors through joint compression provided by weight bearing in proper alignment, 5) altered muscle length resulting in change in resistance to passive stretch, and 6) improved recruitment and sequencing of muscle activity. The literature in this area, however, is limited and controversial.[18]

Difficulty in interpreting the literature occurs because responses to prolonged stretch differ in healthy subjects and in subjects with hyperreflexia. Clinically, it appears that use of the TIAFO, like the use of inhibitory casting, may contribute to more appropriate patterns of muscle coordination, providing external stability with correct biomechanical alignment so that patients no longer need to use an abnormal increase in muscle activity to compensate for lack of stability.[18,19]

The results of our study suggest that the TIAFO may be of value for individuals with neurological deficits. When used with adults, the advantages of inhibitory orthoses over casts include the decrease in weight of an orthosis compared with a cast; the ability of the orthosis to fit inside a shoe; and the adult's stable foot size, which results in little need to adapt the orthosis for foot growth.

We believe a possible disadvantage of the TIAFO over a more traditional AFO is the need for the therapist to be familiar with the movement, hyperreflexia, and response to inhibition of the patient in order to accurately fabricate the footboard and make appropriate recommendations regarding construction of the orthosis. Additionally, effective use of the orthosis by the patient generally requires incorporation of the orthosis as an adjunct into an active physical therapy program.

Further evaluation of the effectiveness of the TIAFO is needed and should include direct replications of this study using hemiparetic patients studied under the same controlled conditions. Additional study is also needed to establish the validity of the EDG system. The system has face validity, but no information on construct or criterion-based validity was found beyond that reported by the manufacturer.[13] The mechanical properties of the measurement system have not been documented in a peer-reviewed publication. Once the validity of the EDG system has been demonstrated, further replication[12] could then be done, involving patients with various types of neurological deficits, as well as comparison of the TIAFO with several types of commonly prescribed AFOs such as the custom-molded polypropylene AFO and the double upright AFO. A series of systematic replications would provide a basis for generalizations regarding the use of the TIAFO with various types of patients at different levels of function and with fabrication of the TIAFO by different therapists and orthotists.

Conclusion

The results of this study suggest that more factors may be responsible for the relative success of an orthotic device than have generally been considered in conventional orthotic management of hemiparetic adults. Use of the TIAFO, with its greater attention to support and alignment of the foot, resulted in significant improvement in ambulation in this single-subject study.

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